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DIAGNOSTIC BUDGETS OF ANALYZED AND MODELLED TROPICAL PLUMES

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1. INTRODUCTION

Blackwell et al. (1991) successfully simulated tropical plumes in a global barotropic model valid at 200 mb. The plume evolved in response to strong equatorial convergence which simulated a surge in the Walker Circulation. The defining characteristics of simulated plumes (See Fig. 1) are:

- i) A subtropical jet with southerlies emanating from the deep tropics
- ii) A tropical/mid latitude trough to the west
- iii) A convergence/divergence dipole straddling the trough
- iv) Strong cross contour flow at the tropical base of the jet.

Diagnostic budgets of vorticity, divergence and kinetic energy are calculated to explain the evolution of the modelled plumes. Budgets describe the unforced (basic) state, forced plumes, forced cases with no plumes, and ECMWF analyzed plumes.

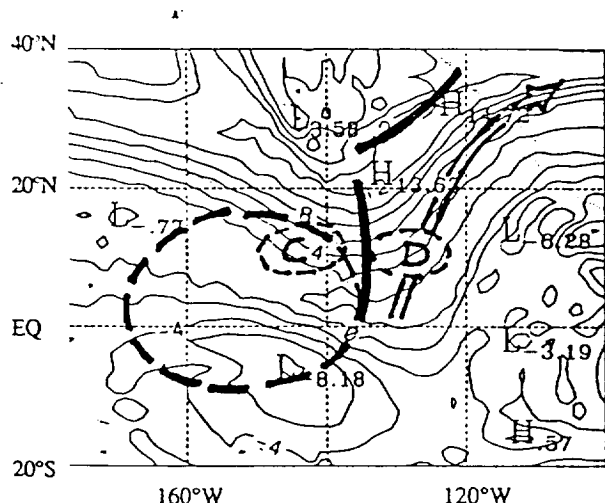


Fig. 1. Absolute vorticity (contour interval $2 \times 10^{-5} s^{-1}$), streamline trough axis (heavy solid), jet (double solid), convergent forcing (heavy dashed) and divergent dipole (dashed) for tropical plume.

2. MODEL PLUME BUDGETS

The vorticity budget describes plume evolution as a two step process. The convergent forcing triggers a large-scale equatorial Rossby wave (Fig. 2). As it grows, it draws a region of strong climatological vorticity gradient equatorwards, particularly near the interaction between the wave's cyclonic flow and an associated mid latitude trough. As

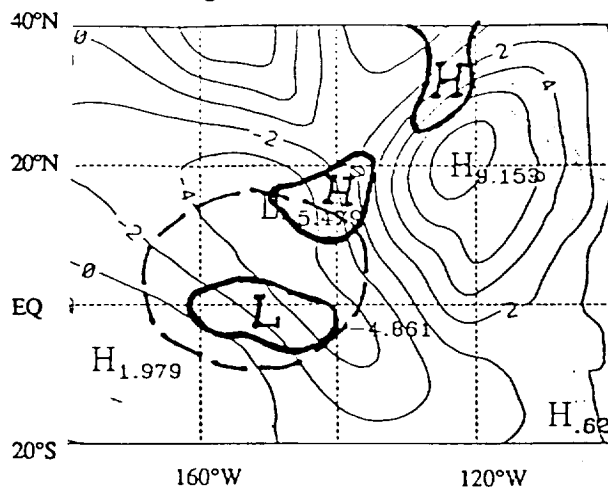


Fig. 2. Rotational advection of planetary vorticity (LHS, contour interval $0.2 \times 10^{-10} s^{-2}$), and divergent source term (RHS, heavy) in vorticity budget. Convergent forcing dashed.

this gradient enters the convergence region, it triggers a second, smaller scale Rossby wave source (stretching plus vorticity advection by the divergent wind). A Rossby wave train propagates mortheastward along the vorticity gradient. Because of the small Rossby radius of deformation, this wave train is strongly divergent.

The divergence budget shows that the ageostrophic forcing (the extent to which gradient balance does not occur) and the divergence advection do not cancel, resulting

in a divergence tendency which excites convergence on the flank of the initial forcing and a divergent center downstream (to the northeast).

The kinetic energy equation shows that the strong cross contour flow accelerates winds into the jet in the divergence center east of the trough and at the base of the jet stream (Fig. 3). Most of the acceleration is caused by a non-divergent work term, cross-contour flow by the rotational wind. This flow develops because the height field in the trough deepens much more rapidly than the wind field can respond, as implied by the small Rossby radius.

This mechanism results in plumes whenever the cyclonic portion of the initial forced Rossby wave is sufficiently close to a mid latitude trough to draw the vorticity gradient into the initial forced region. When a mid latitude trough is not located appropriately (See Fig. 4), a divergent Rossby wave train can still propagate into mid latitudes, but it is not coupled to the subtropical jet and only weak response occurs. Essentially the equatorial Rossby wave and a mid latitude ridge interfere destructively.

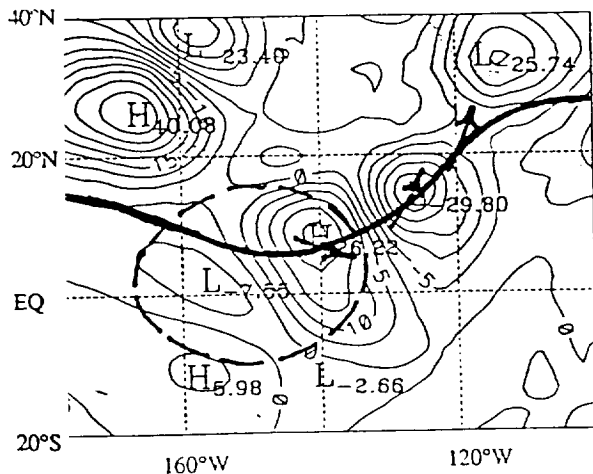


Fig. 3. Work term due to non-divergent wind (contour interval $5 \times 10^{-3} \text{ m}^2 \text{ s}^{-3}$), height contour (heavy) and representative wind vectors.

3. COMPARISONS

The plume experiments are contrasted with ECMWF analysis of tropical plumes, with an unforced model basic state and with forced cases for which plumes did not evolve. Plumes in the ECMWF analysis are weak, their budgets are dominated by "residual terms" and the divergence field is too weak and noisy to analyze. Modelled plumes are contrasted with the forced no-plume case in Fig. 4. Although a strong equatorial response is observed, the vorticity gradient does not strengthen or deflect into the tropics, the trough does not amplify, and the divergent dipole is deflected northward.

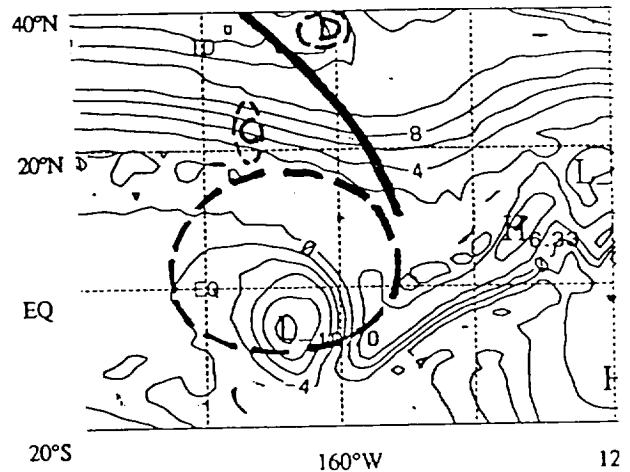


Fig. 4. Absolute vorticity as in Fig. 1 for no-plume case.

4. REFERENCE

Blackwell, K.G., J.P. McGuirk and Y Zhang, 1991: Tropical plumes in a barotropic model, AMS 8th Conf. on Atmospheric and Oceanic Waves and Stability, Denver, 416-417.

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